ITS Tools and Facilities

Advanced Communications Technology Satellite Test Facility

The ITS Advanced Communications Technology Satellite (ACTS) test facility consists of a complete ACTS earth station (ES), provided through a Memorandum of Understanding with the National Aeronautics and Space Administration (NASA), and associated digital interface and test equipment. The experimental Ka-band ES is capable of 1.8-Mbit/s integrated services digital network (ISDN) communications and provides full-mesh connectivity with other ACTS ES's. The digital interface equipment includes a narrowband ISDN switch, narrowband ISDN interfaces and terminal adaptors, an ATM switch, and associated ATM network interfaces. The test equipment includes two data communication test sets and three voice quality assessment systems. The data communication test sets are UNIX work stations that implement ITS-developed, standard data communication performance measures. Associated satellite clocks allow precision time stamping of performance-significant events. The voice quality assessment systems consist of desktop and laptop personal computers and digital signal-processing boards controlled by ITS-developed software that implements innovative perception-based quality measurements. The ACTS test facility is available for Government, industry, and university use as approved by the NASA ACTS Experiment Office.

Audio Quality Laboratory

The Audio Quality Laboratory supports the Institute's audio quality research and standards development. The laboratory equipment allows high-quality recording, subjective and objective analyses, and reproduction of audio signals. Subjective analyses are conducted in an acoustically isolated and treated room that conforms with international recommendations for subjective listening and viewing tests. Test participants hear test material through headphones or loudspeakers and use an electronic pen to record their responses on a small screen. Workstations equipped with 16-bit digital-to-analog converters control the reproduction of test material and the collection of responses.

Also available in the Audio Quality Laboratory are digital audio tape recorders, compact disk players, digital audio encoders and decoders, a spectrum analyzer, signal generators, level meters, mixers, amplifiers, and microphones. Together, this equipment allows ITS staff and cooperative research partners to determine the impact of various coding and transmission systems on the perceived quality of audio signals. This equipment also allows staff to develop and test objective measurements of the perceived quality of audio signals. The Audio Quality Laboratory is connected with the Video Quality and Digital Networks Laboratories. These connections enable integrated testing of multimedia communication systems that transport audio, video, and data communications.

Digital Sampling Channel Probe

ITS, in a joint effort with Telesis Technology Laboratory, has developed and patented an innovative digital sampling channel probe (DSCP). The probe, consisting of both a transmitter and receiver, is used to make complex impulse response measurements of outdoor communication channels and in turn to determine the wideband propagation characteristics. Such measurements are used for modeling and simulation. Unlike the analog sliding correlator equivalent, the DSCP is capable of impulse response acquisitions within the period of 1 pseudorandom noise code word length (typically 51 μs). Used extensively for channel characterization of cellular and personal communications services, the probe typically has been configured for a null-to-null bandwidth of 20 MHz, providing a delay resolution of 100 ns and a maximum measurable delay of 51 μs. Bandwidths as large as 50 MHz also have been used. Currently, the probe has a dual channel capability, making it possible to measure simultaneously two different pseudorandom noise codes on different carrier frequencies, with different antenna polarizations, or with different antenna spacings. By using synchronized timing, it can measure absolute time-of-flight from transmitter to receiver. In addition, it has the capability to acquire multiple impulse responses in succession and thus determine Doppler spread at high vehicle speeds. The present system has a noise figure of 7 dB and when used with an automatic gain control is capable of measuring signals within a range of power seen in cellular sites characterized by severe multipath and shadow

fading. Concurrent acquisition of a global positioning system has given the system the capability of marking the data with speed and location.

New DSCP systems currently are under development. These include a VME system with rapid acquisition for extended periods of time and real-time processing of impulses. A wide bandwidth system (1 GHz null-to-null) also is under development and is particularly suited for indoor measurements where high resolution is required. Future plans include expanding the probe to more channels for use in measurements helpful in analyzing the potential benefits of adaptive antenna arrays. For further information, see the description at the following web site address: *http://www.its.bldrdoc.gov/pub/chprobe/chprobe.html*.

HF Communications System Test and Evaluation Facility

The primary components of the ITS HF Communications System Test and Evaluation Facility are (1) audio compact disk (CD) equipment and software for testing HF radio automatic link establishment (ALE) interoperability; (2) HF network simulators; (3) HF channel and modem software simulators; and (4) narrowband and wideband HF real-time hardware channel simulators. This facility focuses on performance and interoperability testing, particularly on testing HF communications systems related to National Security Emergency Preparedness. The facility also is particularly useful in conducting the proof-of-concept testing that is a critical part of the standards development process.

The audio CD equipment and associated software are used to test ALE protocols and techniques for adaptive HF radios as defined in Federal Standard 1045A. All ALE radios procured by the U.S. Government must perform the functions defined in this Standard. This ensures that all ALE radios will interoperate successfully regardless of vendor. Since each radio system must be tested feature-by-feature to verify its interoperability, ITS has developed a digital audio CD for ALE interoperability testing to ensure uniform, standardized conditions and repeatable results. This reference interpretation and implementation of Federal Standard 1045A is available to all Government agencies, industry, and other ALE users. With a standard audio CD player, anyone can use the ALE CD to test a radio against Federal Standard 1045A. The test is performed by connecting the headphone jack output of the player to the voice-activated input of an HF transceiver. By playing a selected portion of the CD, the transceiver transmits a call to an ALE radio under test.

The HF network simulators are a pair of tools that includes a discrete event simulation model for HF ALE radio networks, and a network protocol simulator. The discrete event simulation model is a computer program used to determine the effects of periodic sounding on network operation. The network protocol simulator is a real-time digital signal processor that simulates HF ALE radio network operation. This latter simulator is very useful for the evaluation of advanced HF networking protocols.

The HF channel and modem software simulator consists of software modules for ALE protocol-testing, error-correction, and linking-protection techniques used in ALE radios. Through simulation studies using these products, throughput and delay effects of advanced networking features such as sounding, polling, direct and indirect message routing, automatic message exchange, and store-and-forward message exchange can be determined. System users and administrators can use these results to chose the proper mix of newly developed advanced network features and functions to achieve maximum channel efficiency. These results also are useful to HF ALE radio users, standards developers, network designers, and radio manufacturers and vendors.

The real-time hardware channel simulation capability consists of a conventional narrowband (Watterson Model) channel simulator and a wideband channel simulator. The latter simulator was developed recently at ITS and has a unique capability for simulating the channel conditions encountered on HF communication links in order to evaluate the performance of HF radios under a variety of repeatable, controllable conditions. The wideband channel simulator employs state-of-the-art digital signal-processing technology to implement new mathematical models of the propagation, noise, and interference environments. Unlike past HF channel simulators that are only valid over narrowband (several kHz bandwidth) channels, the new simulator is based on a fundamentally new approach that enables the simulation of wideband (on the order of 1-MHz bandwidth) as well as narrowband channels, both disturbed and nondisturbed. The HF channel simulator is used to test the operation of complex state-of-the-art HF systems over simulated HF transmission paths. This includes testing systems that use robust transmission algorithms such as code-combining,

Golay, and other forward-error correction codes with either broadcast or automatic repeat request modes.

The test facility has been used for interoperability and performance testing of advanced HF modems and ALE systems. For example, the facility has been used to conduct proof-of-concept testing of robust, high-speed systems such as the proposed Federal Standard 1052, "Data Link Protocol." The facility also has been used in tests needed by the National Communications System, the National Reconnaissance Office, and the Federal Emergency Management Agency. In one test, ITS staff members compared modems that employ simple, cost-effective protocols such as PACTOR, AMTOR, ARTOR, SITOR, CLOVER II, ALE, and G-TOR to determine their suitability in emergency situations.

Integrated Networks Simulation Environment

Computer-based simulation is used widely in performance prediction and design optimization in the field of telecommunications engineering. ITS is expanding its telecommunications modeling and simulation capabilities through the development of a comprehensive laboratory environment for *network-level* simulation. The modeling and simulation tools available in the Institute's network-level simulation environment include the object-oriented Optimized Network Engineering Tools (OPNET) program; the Block Oriented Network Simulation (BONeS) program for developing, executing, debugging, and analyzing simulation models; and several ITS-developed network-monitoring and analysis tools. These programs are hosted on Silicon Graphics, SUN, and NT workstations in a networked environment to allow sharing of resources. The OPNET, BONeS, and ITS-developed network simulation tools have flexible capabilities for modeling and testing complex telecommunications networks including Ethernet and FDDI local area networks, packet- and circuit-switched networks, asynchronous transfer mode networks, satellites links, and other systems.

Integrated Networks Test Bed

This facility provides integrated services digital network-switching and emulation capabilities, and a wide range of facilities to support broadband network testing. The most recent addition is real-time asynchronous transfer mode (ATM) switching capability. In conjunction with a broadband network emulator that implements synchronous optical network and synchronous digital hierarchy (SONET/SDH) transmission protocols, this capability enables researchers to study the effects of transmission errors and traffic loading on ATM network performance. The ATM switches can route live streams of digitized audio, video, or other digital information through SONET/SDH equipment operating at transmission speeds up to 155 Mbit/s. The laboratory is interconnected and interoperable with the Audio Quality and Video Quality Laboratories (described separately in this section). Future applications of this group of integrated laboratories will support the development of performance standards pertaining to multimedia communications.

ITS Local Area Network

ITS maintains a state-of-the-art local area network (LAN) to provide public information services via the Internet, and also to support intranetworking services and laboratory interconnection requirements. The ITS World Wide Web Home Page at *http://www.its.bldrdoc.gov/* features on-line publications and project and personnel information. The ITS anonymous FTP site at *ftp.its.bldrdoc.gov* also provides on-line reports and standards working group information. From these sites one can access special features such as the on-line *Glossary of Telecommunication Terms* (Federal Standard 1037C), or download a complete CD-ROM of HF automatic link establishment tones.

The LAN's structured cabling system interconnects all offices and laboratories with both optical fiber and Category 5 twisted-pair cabling to support high-bandwidth communications on demand. Nearly 200 devices are supported on the Ethernet. Connections also may be made to laboratory test beds featuring synchronous optical network/asynchronous transfer mode and 100Base-TX fast Ethernet facilities. This provides ITS with unique flexibility and quick turnaround time to respond to new programmatic needs.

Intranetworking services include both client-server and peer-to-peer support for 180 personal computers, UNIX workstations, X-terminals, Macintosh computers, and printers in an open-systems environment using the TCP/IP suite with Network File System (NFS) and Session Message Block (SMB) protocol services. The network is managed using the simple network management protocol (SNMP). For more detailed information regarding ITS information services or network technology, please contact Darren L. Smith, Network Manager, (303) 497-3960 or e-mail dsmith@its.bldrdoc.gov.

Laboratory Atmospheric Simulator

ITS has a unique atmospheric simulator facility to measure the radio refractive index of moist air. A computer-controlled environmental chamber, resonator, and millimeter-wave vector network analyzer provide highly accurate measurements of attenuation and phase delay in the 10-220 GHz frequency range. The simulator permits the pressure to be varied over six orders of magnitude (0.001-103 millibars), the relative humidity to be varied between 0 and 100%, and the temperature to be varied between 270 and 320 K. The simulator provides a means of conducting millimeter-wave propagation experiments in a controlled environment that can represent atmospheric heights from the earth's surface to 120 km. This latter height provides a realistic basis for experiments that are representative of satellite heights for most applications. This tool is available for use by private parties on a reimbursable basis.

Microwave Line-of-Sight and Troposcatter Channel Probes

ITS has constructed hardware channel probes to measure multipath on both line-of-sight and troposcatter communication links. Multipath is a radio communication channel impairment in which two or more replicas of a transmitted signal are received at slightly different times as a result of reflections, scattering, or atmospheric refraction in the channel. Multipath changes dynamically and can substantially deteriorate radio performance. The ITS channel probes measure multipath by injecting an RF signal, modulated by a digital pseudorandom sequence, into the channel and cross-correlating the received sequence with a replica of the transmitted one.

Mobile Millimeter-wave Measurement Facility

ITS maintains two measurement vehicles capable of radio channel characterization over a wide frequency range. Both vehicles are equipped with on-board power, telescoping masts, azimuth elevation controllers, and global positioning systems with dead-reckoning backup. A suite of measurement equipment also is available for use in these vehicles. This includes wideband systems for measuring radio channel impulse response at 900 MHz, 1.8 GHz, and 30.3 GHz, as well as additional narrowband measurement capabilities up to 96 GHz. Most recently, these facilities have been used for characterizing radio channel impulse response and Doppler spectrums for cellular radio at 915 MHz, and proposed personal communications services at 1.8 GHz. Millimeter-wave measurements also have been made over a 1-GHz bandwidth centered at 30.3 GHz to characterize proposed local multipoint distribution service radio channels. These vehicles and equipment allow ITS to provide industry with site-specific measurements to support the development of new radio communication technologies.

Radio Spectrum Measurement Systems

ITS has built and operates a number of spectrum measurement systems. The radio spectrum measurement system (RSMS), ITS' primary system, provides a vehicularly mounted, self-contained capability for measurements between 1 MHz and 19.7 GHz. ITS also has available several suitcase-deployable systems, called compact radio spectrum measurement systems (CRSMS), which can be used across the same frequency range. The RSMS and CRSMS incorporate a combination of commercially available hardware, hardware custom-built by ITS, and control software written by ITS. The RSMS is RF-shielded, and includes two 30-ft masts, an on-board 10-kW generator, air conditioners, four equipment racks, and storage space. CRSMS capabilities include the same software as the RSMS, but typically include only as much hardware as is required to perform a particular measurement. Local arrangements must be made for CRSMS shelter and power.

RSMS and CRSMS use extensive computer control for measurements. RSMS and CRSMS measurements can be performed in fully automatic, semiautomatic, and fully manual modes. Mobile radios, fixed communication links, radars, ISM devices, broadcast signals, and special-purpose transmitter systems can be measured. For a complete description of the RSMS, see Appendix A of F.H. Sanders, et al. (1996; see ITS Publications in FY 1996).

Table Mountain Radio Quiet Zone

This unique facility (one of only two in the nation) is controlled by public law to keep the lowest possible levels of unwanted radio frequency energy within the test area. This allows research concerned with low signal levels, such as from deep space, extraterrestrial low-signal satellites, or very sensitive receiver techniques, to be conducted without the interference found in most areas of the nation. As the use of electronic systems (e.g., garage door openers, computers, citizen band radios, cellular telephones, arc welders, and microwave ovens), the number of radio and television stations, and new uses for the radio

frequency spectrum increases, the average level of electromagnetic energy across the spectrum will increase. This is important to companies that develop sensitive radio receivers and signal-processing equipment, since the equipment is often saturated by the background signal level. This facility is available for use by private parties on a reimbursable basis.

Telecommunications Analysis Services

Telecommunications Analysis Services (TA Services) provide the latest engineering models and research data developed by ITS to industry and other Government agencies. TA Services is interactive and computer-based, and is designed to be both user-friendly and efficient. It offers a broad range of programs that allow the user to design or analyze the performance of telecommunications systems. Currently available are: on-line terrain data with 3-arc-seconds (90 m) resolution for much of the world and 5-min resolution data for the entire world; the 1990 census data; Federal Communications Commission (FCC) databases; and geographic information systems (GIS) databases (arcinfo). Other Government databases and reports are available through a bulletin board service available to all users of TA Services as they are developed. TA Services is currently developing models in the GIS environment for personal communications services (PCS). The following is a brief description of some programs available through TA Services.

PATH PARAMTRS - Calculates Great Circle distances and bearings between user-specified locations, and also provides delta-H and average terrain heights for those locations.

RAPIT - Provides on-line access to the latest in VHF/UHF propagation models. It can calculate basic transmission loss and other engineering information, such as received signal levels over irregular terrain for the design or analysis of broadcast and mobile radio systems. These program options allow a user to review the effects that input parameters, such as antenna height, have on the received signal.

FCCFIND, FMFIND, TVFIND, AMFIND, and TOWERFIND - Allow a user to search the FCC database for particular stations or by search radius around a point of interest.

INMOD - Calculates and lists intermodulation products in a user-specified receiver bandpass from up to 40 transmitters, 40 receivers (up to seventh order), and with up to 5 concurrently operating transmitters.

PROFILE - Extracts path profiles according to user-specified input parameters, such as location and bearing. After the data is extracted, either the individual elevations or an average elevation along the profile can be obtained. A user also can receive plots of the profiles adjusted for various K factors depending upon the intended use of the path. For microwave links, Fresnel zone clearance can be determined easily from the plots so that poor paths can be eliminated from a planned circuit or network.

HORIZON - Plots the radio horizon around a specified location in the U.S.-digitized topographic data. It is generally used for sighting satellite terminals and radars so that terrain-shielding effects and limits on the visible elevations can be determined.

SHADOW - Plots the radio line-of-sight (LOS) regions around a specified location in the United States using digitized topographic data. It shows areas that are LOS to the base of the antenna, areas that are LOS to the top of the antenna, and areas that are beyond LOS to the antenna.

COVERAGE - Calculates the receive signal levels along radials that are spaced at user-defined intervals of bearing around the transmitter. The program lists the contours of signal coverage of the transmitter along each radial and lists distances to user-specified contours for each radial. Either the FCC broadcast rules or the ITS Irregular Terrain Model can be chosen for calculations.

CSPM - Determines the system performance of mobile and broadcast systems in detailed output plots of signal intensity. Plotted outputs either can be faxed directly to the user or plotted in brilliant colors on clear plastic to a specified scale for overlaying on geopolitical maps. This is the most detailed of the signal calculation programs available and uses ITS' Irregular Terrain Model in a point-to-point mode. The FCC rules, as well as other widely available models, also can be chosen. New models are placed on-line within CSPM as they become available. CSPM is capable of combining coverage from several transmitters to show the coverage from a network of stations. Interference regions also can be plotted to determine potential interference from a user-specified transmitter within the area of interest. It shows the population, households, and areas covered within each of the signal ranges. The most ambitious use of CSPM to date involves determining the population covered by education television stations.

Video Quality Laboratory

The ITS Video Quality Laboratory is used to develop and test automated techniques for assessing the quality of video and image data. The laboratory contains both objective and subjective measurement facilities. The objective measurement facilities include (1) several high performance workstations that are used for prototyping and testing the video and image parameters; (2) an ensemble of switcher-connected broadcast quality cameras, video recorders, video monitors, image capture and display equipment, video signal generators, and video coders/decoders (codecs); (3) a 40-GB read/write optical jukebox for storing digitized images; and (4) real-time personal computer-based systems that can perform video quality measurements in the field. In FY 96, significant improvements were added to the video quality measurement software (written in C++) to support expanding video quality studies in national and international standards bodies and associated Government and industry technology assessment needs. These improvements include field-accurate video processing (as opposed to frame processing, used in the prior system); improved spatial and temporal registration of input and output images; and accurate precalibration of the sampled images. The subjective measurement facilities include two sound-proof audio-visual testing rooms (added in FY 96) and an ITU-R Recommendation 500 viewing room. These subjective facilities provide a means for validating objective video and image parameters implemented in computer-based measurement systems. The audio-visual testing rooms will be used for assessing interactive multimedia communications equipment and services. The video quality laboratory hardware and software have been designed specifically to address the difficult problem of assessing digital video systems. For example, video codecs are used in conjunction with network error simulators to generate impaired digital video for objective and subjective quality testing.

Wireless Link Simulation Laboratory

This laboratory at ITS simulates wireless systems and channels to predict performance for data, compressed or uncompressed speech and images, and fax sources. ITS specializes in end-to-end results by performing channel characterization measurements, modeling the measurements, imbedding the models in simulation software, and predicting the system performance via simulation. Typically, predicted speech and image quality are determined as a function of signal-to-noise ratio, carrier-to-interference ratio, and bit error ratio for a selected radio system and channel. Real-time link bit error generator models are available for each simulation used to study the effects of the link conditions on various sources and also may be employed as a link model in wireless network simulation. These capabilities are useful in determining predicted performance of proposed wireless systems and standards and are used to determine design and deployment specifications for these systems.

PC/DOS-based and UNIX-based link software simulation packages and a generic channel simulator software package are available to perform wireless simulations, predict performance, and perform signal processing. Laboratory hardware consists of RISC and Pentium workstations to run simulation and signal-processing software. An audio cassette, S-VHS recorder and players, and S-VHS television monitor are available for storing and demonstrating speech, images, and video images. Programmable digital signal-processing boards and card cage are available to download wireless link simulations for real-time testing of transmitters, receivers, and channel models. A programmable 6-MHz bandwidth hardware channel simulator also is available for testing transmitters and receivers.